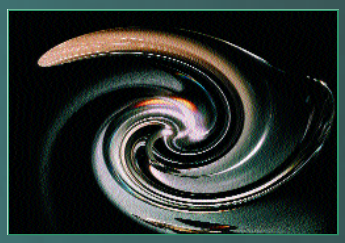
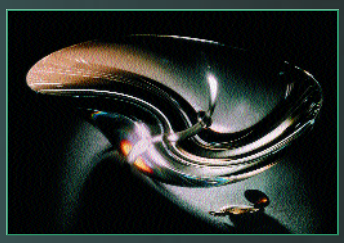
OPTICS


What role do optics play in America's economy? Some important and useful devices depend on optics to produce, control, and detect light in special ways. For millions of Americans who see life as a blur, eyeglasses and contact lenses use optics to focus light so that images can be seen with more clarity. Medical systems see inside the body through precision optical components. And electric utilities are experimenting with optical panels to develop more efficient solar energy collectors, bringing affordable power to many territories.

More sophisticated optics can improve many of these technologies. For ophthalmic equipment, a set of optical mirrors can increase the resolution of retinal cameras, helping researchers identify the biological causes of several eye diseases that can lead to blindness. For electric utilities, new optics panels can improve the efficiency of solar energy conversion, ultimately reducing the cost of electricity for consumers. Unusually shaped optics, called aspheres, offer benefits to a wide range of optical systems, from small image-projection and videography systems to large astronomical telescopes and space surveillance sensors.

Today's Market

U.S. optics companies see signs that the market is growing, so many are adding new employees to explore new opportunities. A recent survey by CorpTech of 88 small U.S. optics companies (fewer than 1,000 employees) reveals that 39 percent of them plan to expand their workforce in 1997; the average anticipated increase is 15.1 percent. The companies expect to create 361 new jobs and generate sales opportunities for their suppliers. More than one company in nine projects growth of more than 25 percent. The highest growth is expected in the Southwest and Eastern Lakes regions, with average increases of 26.6 and 14.8 percent, respectively.[1]

Tomorrow's Opportunity

BMDO has funded the development of precision optics for imaging systems and high-powered lasers that can track and destroy ballistic missiles. Some of the most notable achievements of BMDO technology developers include reducing the cost of optics manufacturing and producing smaller, more sophisticated optical components. These developers, in turn, have found new markets for their optical technologies in such industries as astronomy, holography, and spectrography. The following section highlights six technologies and the companies that are commercializing them.

[1]CorpTech. 1997. Technology spotlight in future employment trends: Photonics-optics and related equipment report. February. World Wide Web at http://www.corptech.com/emptrends/ppho-op.htm.

Can You Imagine . . .

. . . full-color display holograms that add flair to promotional applications.

HOLOGRAPHIC TECHNOLOGY BRIGHTENS A TOWN'S FUTURE

GEARING UP FOR MASS PRODUCTION OF FULL-COLOR DISPLAY HOLOGRAMS, HOLOS OFFERS HOPE FOR A TOWN'S REVITALIZATION.

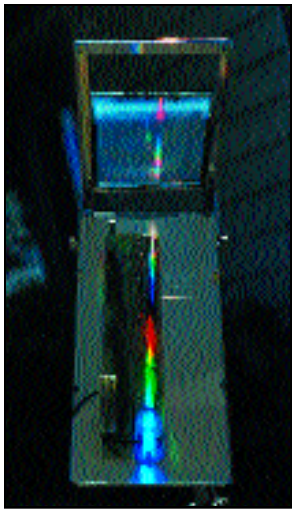
When a producer of medical instruments in Fitzwilliam, New Hampshire, shut its doors in 1994, more than 300 high-tech workers lost their jobs and the entire town felt the repercussions. Then a new manufacturer of holograms, the HOLOS Corporation, set up shop, offering new hope for the town's revitalization. Commercializing BMDO-funded work conducted at Northeast Photosciences (Hollis, NH), HOLOS built on holographic photovoltaics work originally developed to produce solar electricity in space. This work led to HOLOS' production of full-color display holograms.

Often associated with images on credit cards and packaging, holograms represent a growing market. *Holography News*, an international business newsletter of the industry, estimates this market at $200 million in 1995 for embossing alone.[1] However, holography applications extend beyond advertising, packaging, and artistic use into the areas of energy production and conservation. HOLOS currently sells customized full-color displays for promotional applications and expects mass production of full-color displays to begin in mid-1997. The company expects to create at least 60 high-technology jobs in Fitzwilliam within one year of beginning mass production; that number should double as production shifts into high gear.

In some of its more novel applications for its facilities, HOLOS plans to produce holographic films for daylighting. These films will bend sunlight into darkened rooms, allowing building engineers to track and control the amount of sunlight that enters offices. Many expect holographic-coated windows to reduce the need for lighting and air conditioning enough to pay their cost to the consumer in less than a year. A holographic awning, another product in the planning stage, will use treated glass to refract sunlight, brightening the area under it.

HOLOS also plans to produce holographic photovoltaics for terrestrial uses. The holographic device originally developed at Northeast Photosciences greatly improves the efficiency of solar energy conversion, with net conversion efficiencies of up to 30 percent. Arizona Public Service has agreed to host a massive hologram test site for utility-scale power generation. A cost analysis of this technology shows that if one includes environmental cleanup costs with the initial cost of nuclear and fossil fuels, holographic photovoltaic costs are comparable. Holograms could allow solar cells to produce electricity for just five to six cents per kilowatt-hour.

HOLOS has had discussions with a venture capital investor interested in improving the performance of solar cells. The Naval Air Warfare Center at China Lake, California, is interested in using the hologram in SELENE, a program to beam power to a satellite solar power system using a free-electron laser.



■ HOLOS' spectrally sensitive photovoltaic technology, pictured above, greatly improves the efficiency of solar energy conversion.

ABOUT THE TECHNOLOGY

HOLOS' single-element hologram spectrally separates light and focuses it perpendicular to the hologram in a thin concentrated line. Spectrally separating the light, the hologram lets two or more different solar cells absorb only those wavelengths each cell most efficiently converts to electrical power. Only light of high visibility (active radiation) is diffracted to the solar cell, while the undesired infrared radiation totally bypasses the cells, thereby reducing cooling requirements. In addition, the technology's side-by-side design (or side focus) replaces the difficult-to-cool stacked design and improves solar cell efficiency, eliminating shadow effects.

[1]1995: The year holo packaging took off. 1995. *Holography News*. December/January. World Wide Web at http://www.hmt.com/holography/hnews/decjan.htm.

THUMB-SIZED OPTICAL SPECTROMETER COULD BE A HANDY GADGET

Can You Imagine . . .

. . . a micro-optical spectrometer that will allow fiber-optics telecommunications systems to transmit higher data rates efficiently and affordably.

Successful implementation of high-speed fiber-optic data highways depends on the development of state-of-the-art optical devices at reasonable cost. Wavelength division multiplexing (WDM) systems, for example, can transmit multiple wavelength data channels on a single optical fiber. However, WDM systems require expensive technology to sort these wavelengths, spaced as close as 1.6 nanometers apart, for routing purposes.

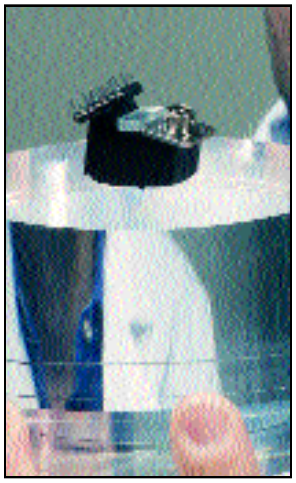
Oak Ridge National Laboratory (ORNL; Oak Ridge, TN) developed a thumb-sized optical spectrometer that offers an affordable solution for WDM and provides optical solutions for many other industries as well. The low-cost microspectrometer can sort light according to wavelengths, allowing fiber-optic telecommunications systems to route multiple data streams easily and efficiently. In a different configuration, the device can detect the presence of a variety of chemicals. These two capabilities open the door to many other applications, such as industrial process control, noninvasive blood chemistry analysis, and environmental and aircraft corrosion monitoring.

The microspectrometer is 6 cm^3 compared with today's television-sized laboratory spectrometers, which can be 20,000 cm^3. In addition, users can tune the rugged device for specific sensing applications. For example, when tuned as a gasoline octane analyzer, it could help alert motorists if any contaminated fuel enters the gas tank. Since it is fully aligned during fabrication (unlike conventional spectrometers), ORNL's device does not require periodic re-alignment. A novel fabrication technique of the microspectrometer lowers its cost. This technique uses specialized diamond-turning equipment originally developed for BMDO through ORNL's Manufacturing Operations Development and Integration Laboratory.

Sensiv, Inc., a manufacturer of infrared optical transmitter probes and remote process monitoring sensors, is the first company to receive a license for the microspectrometer. The company plans to use this technology in a second-generation product for monitoring chemical compositions during materials and pharmaceuticals manufacturing. Company officials project first-generation product availability in early 1997, and expect the microspectrometer's low cost to make the monitoring system more cost-competitive than other systems.

Lockheed Martin, ORNL's operator, now offers nonexclusive licenses in the near-infrared wavelength range of 0.7 to 5.0 microns. It may grant an exclusive license for a specialized application other than general process control and analysis.

SENSIV HAS ACQUIRED THE FIRST LICENSE FOR ORNL'S MICROSPECTROMETER.



■ The 6 cm^3 microspectrometer, pictured above, is much smaller than today's television-sized laboratory spectrometers, which can be 20,000 cm^3.

ABOUT THE TECHNOLOGY

The microspectrometer's design is a modified Czerny-Turner configuration that contains five precision surfaces encapsulated in a single structure. At the entrance surface, the optical fiber collects light and directs it to the collimating surface. The collimating surface redirects the light toward the grating surface. The grating surface disperses the incident light toward the focusing surface, which intercepts the diverging cone of light and focuses it onto the image surface. A detection array attached to the image surface interprets the light wavelengths.

Can You Imagine . . .

. . . a deformable mirror that can help astronomers obtain Hubble Space Telescope–quality imaging with a ground-based telescope.

ADAPTIVE OPTICS BRING SHARPER IMAGES TO ASTRONOMY AND MEDICINE

XINETICS' TECHNOLOGY WON A *PHOTONICS SPECTRA* CIRCLE OF EXCELLENCE AWARD AS ONE OF THE 25 MOST INNOVATIVE PRODUCTS IN 1995.

The atmosphere's turbulent mix of hot and cold air distorts starlight, making it difficult for astronomers to see faint stars through telescopes on earth. Finding a way to compensate for turbulence effects has been a top priority for many in the astronomical community.

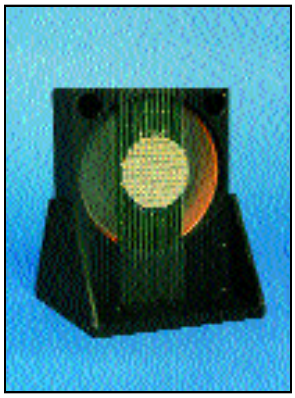
Xinetics, Inc. (Littleton, MA), developed adaptive optics (AO) technology that can help ground-based telescopes probe the mysteries of the universe with 20/20 vision. This technology is based on a deformable mirror system that, with additional AO components, performs real-time compensation for distortions in the optical path. It achieves this compensation through a series of actuators that deform the mirror into different shapes. In 1995, Xinetics' technology won a *Photonics Spectra* Circle of Excellence Award as one of the 25 most innovative products of the year.

AO technology is particularly attractive to astronomers trying to obtain Hubble Space Telescope–quality images with a ground-based telescope. For example, Xinetics' 37-actuator deformable mirror maintained its optical figure (flatness) at 0°C on the mountaintop site of the Keck Observatory in Hawaii. A 349-actuator mirror is also in development for Keck. Under a Hughes Danbury Optical Systems subcontract, Xinetics has built a 941-actuator mirror for the U.S. Air Force's Starfire Optical Range, and is building a similar mirror for the Advanced Electro-Optical System observatory, also located on Mount Haleakula, Hawaii.

In addition to astronomical telescopes, Xinetics uses its AO technology to enhance the image quality of medical and photonics equipment. For example, the company teamed with researchers at the University of Rochester to improve the resolution of a retinal camera. The camera, which analyzes laser light reflected out of the eye, could help the researchers better understand the biological causes of macular degeneration and retinitis pigmentosa, two common eye diseases that can lead to blindness. Researchers integrated a Xinetics' mirror into the AO system, which corrects light distortions coming from the eye.

In another collaboration, Xinetics is developing a distortion-control device for laser film recorders to improve high accuracy scanning, clearing up aberrations from thermal effects. The company expects this teaming effort to produce filmless x-ray technology for medical uses. Working with a leading producer of industrial bar-code scanners, Xinetics is also building an optical corrector that allows scanners to read any size bar code on both small and large packages.

BMDO's ground-based laser program required advanced optics to view space objects clearly and funded much of Xinetics' AO technology to meet this need. Recently, Xinetics has been supported by two new BMDO SBIR Phase I contracts: one for developing a monolithic multilayer actuator module, and the other for developing an adaptive pumping technology for laser mirrors.



■ Xinetics' deformable mirror, pictured above, performs real-time compensation for distortions in the optical path.

ABOUT THE TECHNOLOGY

Key elements of Xinetics' AO technology—piezoelectric or electrostrictive actuators made with lead magnesium niobate (PMN) crystals—expand and contract during application of an electric field, pushing and pulling the mirror into different shapes. Historically used as the preferred piezoelectric material, lead zirconate titanate (PZT) exhibits large hysteresis (cyclical energy lost because the process is not totally reversible), creep, and aging effects. PMN, originally developed at Pennsylvania State University in the late 1970s, overcomes the deficiencies of PZT, making it attractive for adaptive mirrors because of its high stiffness, negligible hysteresis, and excellent stability.

SPACE OPTICS FIND DOWN-TO-EARTH APPLICATIONS

Can You Imagine . . .

. . . automated techniques that reduce the manufacturing cost of precision aspheric optics.

The famous repair of the Hubble Space Telescope illustrates the utility of precision optical components. The National Aeronautics and Space Administration built the telescope, designed to reveal the outer reaches of the universe, at a cost of $1.5 billion and launched it in 1991. In orbit, however, the telescope's flawed primary optics greatly impaired its vision. Correcting Hubble's optics required fabricating and installing several nonspherical optical components called aspheres. With these components, Hubble's enormous telescopic power achieved its designed capacity.

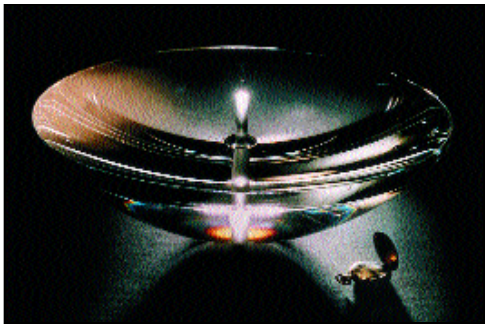
Other fields also demand precision aspheres. The asphere, whose surface can be tuned to a specific application, opens up many advantages to the optical designer, among them reduced weight and size and improved light throughput. However, the aspheres' high cost and the difficulty of making them have limited their widespread use in commercial applications. With the help of BMDO funding, Tinsley Laboratories, Inc. (Richmond, CA), developed sophisticated automated manufacturing techniques to make aspheres more efficiently.

Grinding and polishing tools and the accuracy of measurement tools previously limited the fabrication and testing of aspheres. Tinsley's techniques combine high-speed equipment with computerized control to automate these processes, saving one-third of the time needed to build and test aspheres and making new applications economically feasible. Applications for Tinsley aspheres range from tiny lenses for image projection and videography to large optics for astronomy and space surveillance sensors.

Tinsley expects its collaboration with Lawrence Livermore National Laboratory (Livermore, CA) to result in new ultraprecision aspherical optics for microlithographic and laser fusion applications. The team will be developing new technology for the precision optics required for the next generation of "steppers," machines used to manufacture computer chips. In another project, Tinsley is developing aspheric focus lenses for the laboratory's experiments in inertial confinement fusion.

TINSLEY HAS INTRODUCED A WIDE-ANGLE ASPHERE AS A COMPACT, LIGHTWEIGHT ACCESSORY TO VIDEO-CAMERA LENSES.

Through its recent acquisition of Century Precision, Tinsley supplies advanced optical products, including aspheres, for cinematography, the professional video market, and gyrostabilized video cameras for television news and sports coverage. The company has already introduced a wide-angle adaptor consisting of a single-element, two-sided asphere as an accessory to video-camera lenses. The asphere provides a wide-angle image without adding to the distortion of the camera, and videographers appreciate its compact, lightweight design.



■ This oddly shaped lens was designed to concentrate light for a laser-fusion project.

ABOUT THE TECHNOLOGY

Developed in the BMDO-sponsored Aspheric Surfacing Technology (AST) program, Tinsley's techniques include computer-controlled optical surfacing, high-speed profilometry, and phase-measuring interferometry. BMDO's plan to develop a fleet of missile-tracking satellites required precision optical components for sensor-based surveillance systems.

The computer-generated hologram (CGH) risk-reduction experiment provided a key to the AST program. In the past, combinations of spherical and cylindrical optics canceled out the aberrations normally produced by the aspheric optic. CGH technology, long viewed as an attractive alternative to multiple optics, proved difficult to implement in the manufacture of complex aspherics. However, Tinsley's AST-funded CGH successfully demonstrated the feasibility of using a CGH as a null corrector to test aspheric optics for defects.

Can You Imagine . . .

. . . a tracking system that can tell in what direction and at what depth the eye is focusing.

3-D EYE TRACKING TO AID VIRTUAL ENVIRONMENTS TECHNOLOGY

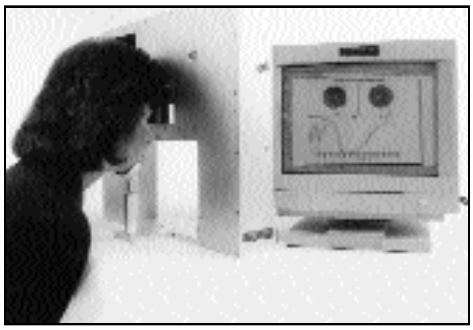
Projecting images where the user's eyes look, and not just where the head points, creates a more realistic virtual environment for flight simulators, virtual reality (VR) displays, and helmet-mounted displays. This function requires new technology to track the eyes' movements and focusing distances in real time. The new ocular information would enable computers to precisely locate where the user looks. It also would allow the computers to project low-resolution images in areas where the user's eyes are not focused, saving valuable computer time.

Applied Modern Technologies Corporation (AMT; Huntington Beach, CA) developed a real-time device that tracks critical eye movements and measures important physical characteristics of the eye. The next generation of VR displays and telemedicine systems could incorporate this device, which is called OVAS® (short for ocular vergence and accommodation sensor). OVAS is derived from BMDO-funded research and development in adaptive optics.

AMT MARKETS A VERSION OF OVAS® SUITABLE FOR USE IN AN OFFICE OR LABORATORY.

AMT's technology could significantly improve VR displays. Feeding viewer sight information to image generators, OVAS could reduce the cost of VR displays, since computer resources will not be spent generating images in areas outside the viewer's focus. Because it can help image generators to precisely position the virtual scene before the viewer's eyes, OVAS could also increase the sophistication of VR displays.

AMT markets a version of OVAS for VR suitable for use in an office or laboratory. Currently housed in a box that fits on a tabletop, OVAS weighs approximately 10 pounds. It could be miniaturized to 20 grams per eye, with a size approximately 1 x 6 inches for helmet-mounted displays or goggle applications. Because OVAS takes readings from up to four feet away from the subject, AMT envisions application in VR theaters, rides, or games.



■ AMT's OVAS® projects near-infrared light on the retinas to tell where the eyes are focused.

As part of a telemedicine system, OVAS could help doctors diagnose ophthalmic conditions in patients located miles away. AMT plans to build a telemedicine system that incorporates OVAS technology under a proposal to the U.S. Army Medical Research and Material Command. Other research participants include Multimedia Medical Systems, the University of Washington, and the University of Southern California's School of Ophthalmology. In addition, AMT has obtained a two-year grant from the American Health Foundation to apply OVAS in the diagnosis of Alzheimer's disease. Other applications may include ophthalmic research and corneal surgery. AMT will soon seek FDA approval for OVAS.

ABOUT THE TECHNOLOGY

OVAS measures the ocular foci and vergence—or inward pointing of the eyes—faster than the eyes can respond. It also measures pupil size in real time. Using two low-power, near-infrared lasers operating at a wavelength of 840 nanometers, OVAS bounces light off the retina of each eye and through a set of optics. The spectral reflection provides wavefronts of very short spatial coherence length. A wavefront-sensing technique originally developed for BMDO-funded adaptive optics research characterizes the wavefronts. A desktop computer processes this information to extract the refractive power of the ocular system from the wavefronts. OVAS currently operates at data rates between 0.5 and 10 Hertz.

LASER BEACON SHARPENS IMAGES OF EARTH-BOUND ASTRONOMY

Can You Imagine . . .

. . . a laser guide that helps astronomers see the universe with greater clarity from retrofitted terrestrial telescopes.

The science of adaptive optics (AO) is at least as old as the speculations of Sir Isaac Newton on the nature of light scatter. He once observed that good astronomical viewing required a "serene and quiet Air," and for centuries stargazers sought high ground to escape the influence of the earth's atmosphere. Some of the world's most powerful telescopes were built on mountaintops to get a clearer look at the universe and the Hubble Space Telescope represents the latest extension of this quest for clear vision.

In recent years, as defense technology yielded its secrets to the astronomy community at large, the undulations of the air seem more manageable. AO, originally conceived to get a clear view of missile threats and spaceborne weaponry, now provides astronomers with a conjurer's bag of tricks. Shape-changing mirrors, fast digital processors, and powerful lasers help to gather and focus errant light waves. Once indistinct, or even hidden, stars and galaxies will soon be seen with greater clarity from retrofitted terrestrial telescopes.

Lawrence Livermore National Laboratory (LLNL; Livermore, CA) testfired a new sodium laser guide star at Mount Hamilton's Lick Observatory. The guide star is part of an AO system that enables astronomers to sharpen ground-based celestial images to resolutions approaching the quality of Hubble. The LLNL project aims to retrofit some of the world's largest telescopes, including the Keck II telescope on Mauna Kea, Hawaii, with new eyes to see the universe. Its sister, Keck I, has already made significant discoveries about the cosmos. Many expect Keck II to outperform Keck I once it has the high-technology equivalent of corrective lenses.

The U.S. Department of Energy at LLNL originally sponsored the Atomic Vapor Laser Isotope Separation program, whose technology led to the evolution of the high-powered laser. However, BMDO and the U.S. Air Force's pioneering AO research marks the AO system surrounding the laser. Dr. Claire Max, principal investigator, worked on the original concept of laser guide stars in a BMDO-supported AO project in the early 1980s.

A number of AO experts contributed to LLNL's technology development. These experts came from companies such as Xinetics, Inc., Itek, Adaptive Optics Associates, and MIT's Lincoln Laboratory.

A NUMBER OF ADAPTIVE OPTICS EXPERTS CONTRIBUTED TO LLNL'S TECHNOLOGY DEVELOPMENT.

■ A laser guide star is beamed out of the open dome of Lick Observatory. It sharpens ground-based celestial images.

ABOUT THE TECHNOLOGY

The laser guide beams up to a focal point 95 kilometers above the earth. This soldium-rich region of the upper atmosphere fluoresces when the laser beam illuminates it. Knowing the properties of the exciting laser and of the returning sodium light, researchers can map the atmospheric distortions in the signal and compensate for those distortions with AO elements.